Beam Losses and Collimation in VLHC

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Outline

- Compare expected long-term multiturn losses to acceptable ones in superconducting coils.
- Describe two-stage collimation system – Express needs from optics.
- Discuss Single Diffractive losses downsteam experiments – a case of dangerous local single pass losses in VLHC.

All that being a quick first order view of the subject.

Peak energy deposition $\hat{\epsilon}$ per proton in the coil of LHC type magnets

- Impact of primary proton of energy E at betatronic angle
- CASIM simulation at .45 and 7 TeV
- Extrapolation with $\hat{\epsilon} \sim E \ln 5.2E$ (need new simulation)
- Effective shower length $L_{shower} \sim 1$ meter

Beam energy E [TeV]	Peak energy density $\hat{\epsilon}$ $[\mathrm{GeV\ m\ cm^{-3}}]$	Relative peak density $\hat{\epsilon}/\hat{\epsilon}(.45)$ TeV
.45	0.14×10^{-10}	1
3	3.0×10^{-10}	21
7	9.2×10^{-10}	67
50	$100. \times 10^{-10}$	730

Ref. JBJ et al., LHC Project Report 44, CERN 1997.
N.Catalan et al., Proc. Near Beam Physics,Fermilab, 1997.

Losses at Injection and Collision

		Injection, transient	Collision, continuous
	N_p	$\Delta N_{\overline{RF}}$	$\dot{N}_{loss}$
low B	1.2E15	3.6E13	7.8E9
high B	1.4E14	4.2E12	7.8E9

- Considering 3% of a store to be outside bucket (lost at beginning of ramp)
- $\dot{N}_{coll} = 2\, experiments \times \mathcal{L} \times \sigma = 2.6E9\, ps^{-1}$
  ($\sigma_{elastic} + \sigma_{SingleDiffractive}$ close to σ_{total})
- Vacuum such that $\dot{N}_{beam-gas} \leq \dot{N}_{coll}\ (design)$
- Beam dynamics such that $\dot{N}_{dynamics} \leq \dot{N}_{coll}$
- $=> \dot{N}_{loss} = \dot{N}_{coll} + \dot{N}_{beam-gas} + \dot{N}_{dynamics} \leq 3\dot{N}_{coll} = 7.8E9\, ps^{-1}$
- COMPARE TO QUENCH LEVELS

Ref. N.Catalan , LHC Project Report 200, CERN 1998.
G.Dugan,P.Limon and M.Syphers , VLHC Web site,1998?

Basic argument for Collimation:

- Halo protons migrate slowly (transverse or longitudinal) and finally touch the vacuum chamber at few localised aperture limitations.
- Therefore all losses concentrate in few meter long sections, not much longer than the length of their shower ($L_{shower} \approx 1$ m) .
- Considering a single location of null length collecting all primary losses is not much pessimistic – it is our working hypothesis.

Quench levels

We use the heat or power deposition to quench a coil as measured for LHC samples.

- Transient quench levels at $\approx$ null field $\Delta Q_q = 0.35$ [J cm^{-3}]
- Continuous quench levels at high field $\Delta W_q = 5.0\ 10^{-3}$ [W cm^{-3}]

In the low-field option, the coil is quite distant from the vacuum chambers (but is exposed to both beams). Depending on the amount of material located between the coil and the vacuum chamber, the energy deposition $\hat{\epsilon}$ per proton in the coil might be smaller than the values of slide 3. This uncertainty is reflected by a question mark on the next slide.

Ref. JBJ et al., LHC Project Report 44, CERN 1997.
N.Catalan et al., Proc. Near Beam Physics,Fermilab, 1997.

Local Energy or Power Deposition in the Absence of Collimation

3TeV

	Losses transient ΔN $[\mathrm{p\ m^{-1}}]$	Peak Dens. /Proton $\hat{\epsilon}$ $[\mathrm{J\ m\ cm^{-3}}]$	Energy Density $\Delta N \hat{\epsilon}$ $[\mathrm{J\ m\ cm^{-3}}]$	Quench Limit ΔQ_q $[\mathrm{J\ cm^{-3}}]$	Excess Factor $\Delta Q_q/(\Delta N \hat{\epsilon})$
low-B	$3.6\ 10^{13}$	? $3.0\ 10^{-10}$	? $1.1\ 10^{4}$	0.35	? 31000
high-B	$4.2\ 10^{12}$	$3.0\ 10^{-10}$	$1.3\ 10^{4}$	0.35	3600

50TeV

	Loss continuous $\dot{N}$ $[\mathrm{p\ m^{-1}}]$	Peak Dens. /Proton $\hat{\epsilon}$ $[\mathrm{J\ m\ cm^{-3}}]$	Power Density $\dot{N} \hat{\epsilon}$ $[\mathrm{W\ m\ cm^{-3}}]$	Quench Limit W_q $[\mathrm{W\ cm^{-3}}]$	Excess Factor $W_q/(\dot{N} \hat{\epsilon})$
	$8.0\ 10^{9}$	$1.0\ 10^{-8}$	80	$5.0\ 10^{-3}$	16000

Clear need for collimation – betatronic and momentum

Optimum Betatron collimation

- With primary collimators at depth $n_1\sigma_\beta$ and secondary at $n_2\sigma_\beta$, the secondary halo can be cut at $A_{sec} \approx 1.1n_2$ (normalised amplitude). n_1 and n_2 fix the phase $\mu_o = \cos^{-1}(n_1/n_2)$, see table next slide.
- Needs are
  - 3 primary jaws (horizontal, skew, vertical)
  - 4 secondary jaws/primary one $\equiv$ 12 jaws
  - Correlated phase constraints (specification for the optics, see next slide)
- Such an optics yet to be studied
- Needs a straight section with $\Delta\mu_{x,y} \simeq 4 - 6\pi$

Momentum Collimation is a sub-case of Betatron cleaning

- Use one horizontal primary jaws $<=>$ first four lines of next slide
- Need space to built an adequate Dispersion curve in the straight section

Ref: JBJ, Phy.Rev. ST-Acc & Beams,**1**,081001,1998.

Table 1: Secondary collimator locations μ_x and μ_y and $X - Y$ jaw orientations α_{Jaw} for three primary jaw orientations α and four scattering angles ϕ .

α	ϕ	μ_x	μ_y	α_{Jaw}
0	0	μ_o	-	0
0	π	$\pi - \mu_o$	-	0
0	$\pi/2$	π	$3\pi/2$	μ_o
0	$-\pi/2$	π	$3\pi/2$	-μ_o
$\pi/4$	$\pi/4$	μ_o	μ_o	$\pi/4$
$\pi/4$	$5\pi/4$	$\pi - \mu_o$	$\pi - \mu_o$	$\pi/4$
$\pi/4$	$3\pi/4$	$\pi - \mu_o$	$\pi + \mu_o$	$\pi/4$
$\pi/4$	$-\pi/4$	$\pi + \mu_o$	$\pi - \mu_o$	$\pi/4$
$\pi/2$	$\pi/2$	-	μ_o	$\pi/2$
$\pi/2$	$-\pi/2$	-	$\pi - \mu_o$	$\pi/2$
$\pi/2$	π	$\pi/2$	π	$\pi/2 - \mu_o$
$\pi/2$	0	$\pi/2$	π	$\pi/2 + \mu_o$

Collimation – continued : Compute efficiencies

EFFICIENCY CALCULATION:

- Multiturn tacking + True Scattering (K2 code)
- Get 4D-tertiary halo density
- Estimate its dilution along the arc or the exprimental insertions
- Get a loss rate per meter per primary proton touching the jaws
- This value is the collimation inefficiency η_{coll}
- Compare to the inverse of the 'Excess Factor' of slide 7: η_{needed}
- Interpolate LHC η_{coll} data, to be done again for VLHC
  1. LHC at injection $\eta_{coll} = 1.0 \times 10^{-5}$ $[\mathrm{m}^{-1}]$
  2. LHC at top energy $\eta_{coll} = 2.0 \times 10^{-6}$ $[\mathrm{m}^{-1}]$

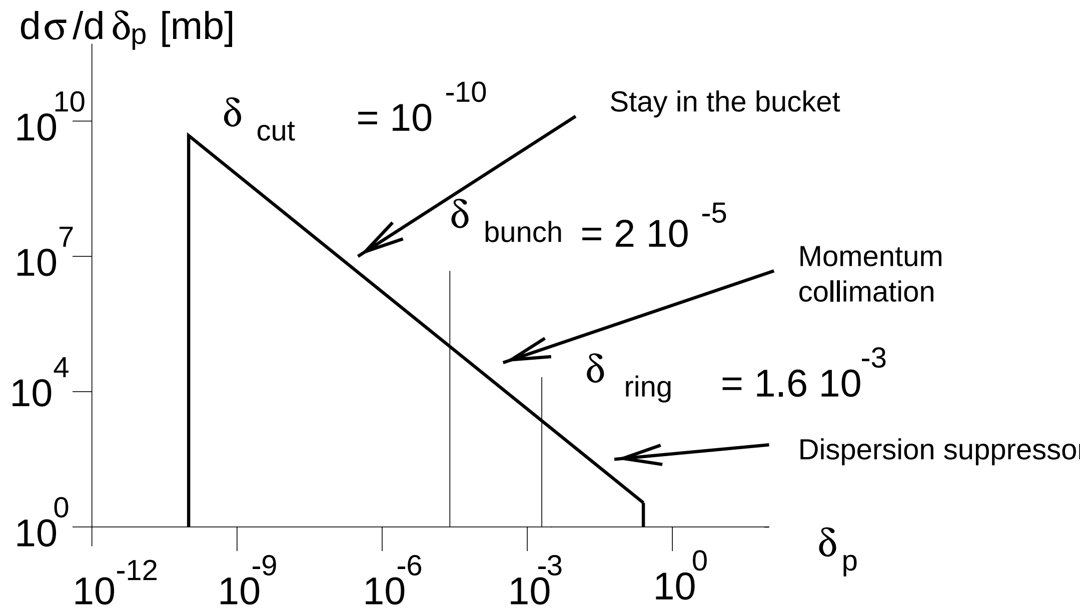
Ref. N.Catalan et al., Proc. Near Beam Physics,Fermilab, 1997.

Collimation Efficiency – continued

Beam Energy [TeV]	Collimation Inefficiency η_{coll} [m^{-1}]	Needed Inefficiency η_{need} [m^{-1}] Low/High field	Margin Factor
3	5×10^{-6}	? $3 \times 10^{-4} / 3 \times 10^{-4}$	? 6/54
50	$\sim 10^{-6}$	$6 \times 10^{-5} / 3 \times 10^{-4}$	60

- The low-field case might be a problem at injection, unless the coil is protected (?).
- At 50 TeV, the aperture limitation is in experimental insertions, not in the arcs, therefore low-B/high-B machines have similar limits.
- All the other cases seem to have an adequate margin – but not too high at 50 TeV – need optimum collimation insertion.
- At 50 TeV, $\sigma_\beta \simeq 0.1 mm$. While the tertiary halo is quite flat in σ_β units the secondary halo is steep. A finite clearance (1 mm ?) is needed between the edge of the secondary halo and the vacuum chamber, once tolerances and closed orbit and so are included (aperture analysis).

Single Diffractive losses in collision



- Differential cross-section $\frac{d\sigma}{d\delta_p} = \frac{a_{SD}}{\delta_p}$ with $\delta_p = \delta_{cut} = [\frac{1}{s}, 0.15]$ and $a_{SD} = 0.7$ mb, integral $\sigma_{SD} = 15$ [mb] at VLHC.
- With increasing $s = E_{CM}^2$ only δ_{cut} changes
- Look at losses in the dispersion supressor - next slide

Ref. JBJ, CERN SL 92-44 (EA), 1992.

Single Diffractive losses in collision - continued

It can be shown that with a constant pipe section and a centered beam, the losses per meter in the dispersion suppressor are given by

$$\dot{n}_{SD} = \mathcal{L} a_{SD} \frac{D'}{D} \text{ with } D \text{ in meter} \quad (1)$$

Using $(D'/D)_{max} = 7 \times 10^{-2}\ \mathrm{m}^{-1}$ (the LHC value)

$$\dot{n}_{SD} = 5 \times 10^5 \text{ proton s}^{-1}\mathrm{m}^{-1} \quad (2)$$

compared to a quench limit

$$\dot{n}_q = 5 \times 10^5 \text{ proton s}^{-1}\mathrm{m}^{-1} \quad (3)$$

With unavoidable orbit and mechanical errors, the quench limit is passed.

POSSIBLE CURE : Built a dispersion $D \approx 0.5$ m in the straight section and collimate at $x = 10\sigma_\beta$, making a cut at $\delta_p = 2 \times 10^{-3}$.

– Might need longer straight sections. Maybe not easy.

– Would allow Single diffractive experiment.

Summary

- Need optimum multiturn Betatronic and Momentum Collimation
- Collimation efficiencies look adequate
- Collimation optics specified but not yet existing
- Single Diffractive losses downstream of experiments need local momentum collimation – would allow Single Diffractive Physics
- need long straight sections in both Collimation and Experimental Insertions